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Smart Dental Caries Detection System

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Abstract: ***DentAI is an intelligent dental screening application designed to detect dental caries (tooth decay) from panoramic X-ray images using deep learning techniques. It utilizes a Convolutional Neural Network (CNN) model trained on dental radiographs to identify radiolucent regions and structural anomalies associated with caries. Built with Streamlit, the system provides an interactive interface where users can upload X-ray images and receive real-time analysis. The preprocessing pipeline standardizes image size and normalizes pixel values before prediction, and the model classifies results into three categories: caries detected, no caries detected, and uncertain, with a confidence score to improve reliability. The application also enhances interpretability by offering detailed explanations and integrates an AI-powered chatbot to answer dental health queries and provide guidance based on the results. DentAI aims to support early detection and preliminary screening, particularly in resource-limited environments, while emphasizing that it is not a substitute for professional dental diagnosis.***

Keywords: Dental Caries Detection, Deep Learning, Convolutional Neural Network (CNN), Panoramic X-ray, Medical Image Analysis, Computer-Aided Diagnosis, Streamlit, Image Preprocessing, Healthcare AI, Dental Screening

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I. INTRODUCTION

Dental caries, commonly known as tooth decay, is one of the most prevalent oral health problems worldwide, affecting individuals across all age groups. Early detection of caries is crucial to prevent severe complications such as tooth loss, infection, and increased treatment costs. Traditionally, dentists rely on visual examination and radiographic analysis, particularly panoramic X-rays, to identify carious lesions. However, manual interpretation can be time-consuming and subject to variability depending on the clinician's experience and workload.

With the advancement of artificial intelligence, especially in the field of deep learning, automated medical image analysis has gained significant attention. Convolutional Neural Networks (CNNs) have demonstrated remarkable performance in detecting patterns and anomalies in radiographic images, making them suitable for dental diagnostics. By leveraging these techniques, it is possible to develop systems that assist dentists in identifying caries more efficiently and consistently.

This project, DentAI, presents an intelligent dental caries detection system that analyzes panoramic X-ray images using a trained CNN model. The application provides real-time predictions through an interactive web interface built with Streamlit, allowing users to upload images and receive instant results along with confidence scores and explanations.

II. RELATED WORK

Recent advancements in artificial intelligence have significantly contributed to the field of dental image analysis, particularly in the detection of dental caries using deep learning techniques. Several studies have explored the use of Convolutional Neural Networks (CNNs) for analyzing dental radiographs, demonstrating high accuracy in identifying carious lesions and other oral abnormalities. These models are capable of learning complex patterns such as radiolucent regions, enamel degradation, and structural inconsistencies from large datasets of annotated X-ray images.

Earlier approaches to caries detection primarily relied on traditional image processing methods, including thresholding, edge detection, and feature extraction techniques. While these methods provided initial insights, they often lacked robustness and accuracy when dealing with variations in image quality and complex dental structures. In contrast, deep learning-based methods, especially CNN architectures, have shown improved performance due to their ability to automatically extract relevant features without manual intervention.

Several research works have also focused on integrating AI- based diagnostic tools into clinical workflows. For instance, systems have been developed to analyze bitewing and panoramic radiographs for early-stage caries detection, assisting dentists in decision-making. Additionally, studies have highlighted the importance of incorporating confidence measures and uncertainty handling in AI predictions to improve reliability and trust in automated systems.

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III. PROPOSED SYSTEM ARCHITECTURE AND METHODOLOGY

The proposed DentAI system integrates a CNN-based deep learning model with a Streamlit web interface for automated dental caries detection from panoramic X-ray images. Uploaded images are preprocessed through resizing, normalization, and RGB conversion before being fed into the trained model for prediction

A. Image Acquisition and Preprocessing

The system begins with the acquisition of panoramic dental X-ray images uploaded by the user through a web- based interface. The preprocessing module ensures that the input image is compatible with the trained model. This includes:

1) Image Conversion: Converting images to RGB format for uniformity.
2) Normalization**:** Scaling pixel values to a range of 0 to 1.
3) Resizing: Standardizing image dimensions to 256 × 256 pixels.

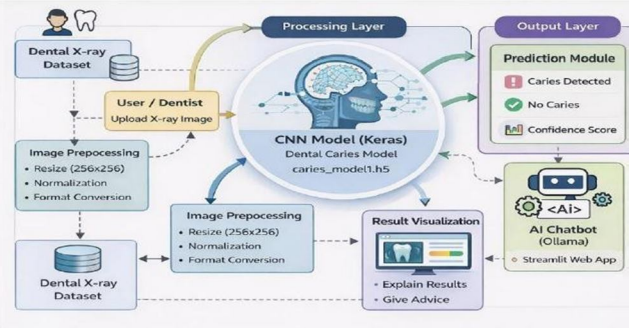


Fig. 1. Block diagram of the proposed system architecture

B. Caries Detection using CNN

The processed image is passed to a Convolutional Neural Network (CNN) model trained on dental radiographic data. The model extracts important features such as radiolucent regions and structural variations to identify potential caries. The output is a probability score representing the likelihood of caries presence.

IV. IMPLEMENTATION DETAILS

The DentAI system is implemented as a web-based application that integrates deep learning with an interactive user interface for efficient dental caries detection. The implementation focuses on building a robust backend for model inference and a user-friendly frontend for seamless interaction and result visualization.

A. System Development and Model Integration

The system is developed using Python with key libraries such as TensorFlow/Keras for the CNN model, OpenCV and PIL for image processing, and Streamlit for the web interface. The trained caries detection model is stored in .h5 format and loaded dynamically within the application using caching techniques to optimize performance. The preprocessing pipeline is implemented to match the training conditions, including image resizing, normalization, and conversion to RGB format. Once processed, the image is passed to the CNN model, which generates a prediction score. The classification logic is implemented using threshold- based conditions to categorize the results into caries, no caries, or uncertain. Additionally, session state management is used to store analysis results and maintain interaction flow within the application.

B. User Interface and Chatbot Integration

The frontend is built using Streamlit, providing an intuitive interface for users to upload X-ray images and view analysis results in real time. Custom CSS styling is applied to enhance visual appearance, including result cards, confidence bars, and structured information sections. The system displays predictions along with confidence scores, explanations, and recommended actions to improve interpretability. An AI-powered chatbot is integrated using Ollama, enabling users to ask dental health-related questions. The chatbot utilizes contextual information from the analysis results to generate meaningful responses and guidance. This component enhances user engagement and provides additional support beyond basic prediction, making the system more interactive and informative.

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V. EXPERIMENTAL RESULTS AND PERFORMANCE ANALYSIS

The performance of the proposed DentAI system is evaluated using a dataset of panoramic dental X-ray images. The Convolutional Neural Network (CNN) model was trained and tested to assess its ability to accurately detect dental caries. The evaluation focuses on metrics such as accuracy, prediction confidence, and system reliability in handling real- world images.

A. Performance Evaluation Metrics

The model achieved an overall accuracy of approximately **94%**, indicating strong performance in classifying dental caries and non-caries cases. The system outputs a probability score, which is further interpreted into meaningful confidence levels for better understanding. In addition to accuracy, the introduction of an **uncertain classification range (0.40–0.60)** helps in identifying borderline cases where the model is less confident, thereby reducing the risk of incorrect predictions.

The system also demonstrates efficient processing time, providing near real-time results for uploaded images. This makes it suitable for practical applications where quick preliminary screening is required.

B. System Performance and Analysis

The DentAI system shows reliable performance in detecting prominent carious lesions, particularly in high-quality panoramic X-ray images. However, variations in image quality, contrast, and incomplete or cropped images can affect prediction accuracy. The uncertain category effectively captures such challenging cases, prompting users to seek professional evaluation.

Furthermore, the integration of explainable outputs improves transparency by providing reasons behind predictions, such as detection of radiolucent areas or structural inconsistencies. The chatbot component enhances the overall system by offering additional insights and guidance based on the results.Overall, the experimental results demonstrate that the proposed system is effective for preliminary dental caries screening, improving diagnostic support while maintaining awareness of its limitations in clinical use.

C. Workflow Improvement

The proposed DentAI system significantly improves the overall dental screening workflow by automating the process of caries detection and preliminary analysis. In traditional methods, dentists manually examine X-ray images, which can be time-consuming and subject to human variability. By integrating a CNN-based detection model, the system reduces the time required for initial screening and assists in faster decision-making.

VI. CONCLUSION AND FUTURE WORK

The proposed DentAI system demonstrates the effective use of deep learning techniques for automated dental caries detection from panoramic X-ray images. By integrating a Convolutional Neural Network (CNN) with a user-friendly Streamlit interface, the system provides real-time analysis, accurate predictions, and explainable results. The introduction of a threshold-based classification, including an uncertain category, enhances reliability and reduces the chances of misclassification. Additionally, the inclusion of an AI-powered chatbot improves user interaction by offering guidance and answering dental health-related queries.

Despite its promising performance, the system has certain limitations, such as dependency on image quality and the use of a relatively limited dataset. In future work, the model can be improved by training on larger and more diverse datasets to enhance generalization. Advanced techniques such as transfer learning, attention mechanisms, and segmentation- based approaches can be incorporated to improve detection accuracy, especially for early-stage caries. Furthermore, integration with real clinical systems and mobile applications can increase accessibility and usability. The system can also be extended to detect other dental conditions such as periodontal diseases and lesions.

In conclusion, DentAI serves as an efficient and intelligent assistive tool for preliminary dental screening, supporting early diagnosis while emphasizing that it is not a replacement for professional dental expertise.

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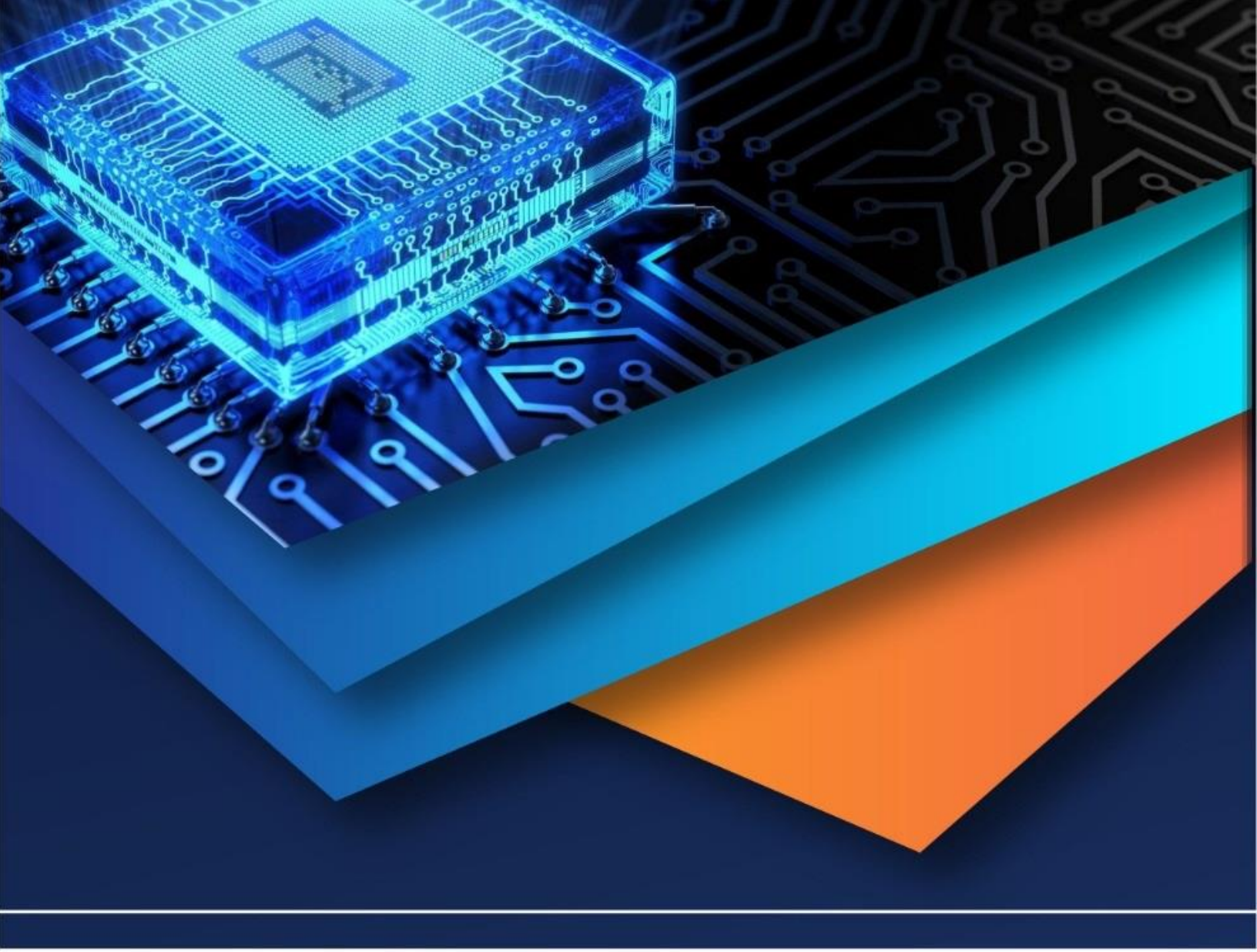
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